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FIRE PROTECTION TESTS IN A SMALL FUSELAGE-MOUNTED TURBOJET ENGINE AND NACELLE INSTALLATION

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FINAL REPORT

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16. Abstract

Tests under simulated flight conditions were conducted on a small fuselage-mounted turbojet engine and nacelle installation to investigate the potential explosion and fire hazards and detection and fire control methods.

Hot-surface ignition of flammables did not occur during simulated flight operating conditions until a change to the normal nacelle configuration reduced cooling airflow to the hot section of the engine (Zone I) below 0.15 pound per second.

The installed detection system did not provide for prompt detection of all fires originated in the lower forward portion of the compressor compartment (Zone II). Both the Zone II fire detection and the Zone I overheat detection system, a portion of which traversed the aft inboard section of Zone II, were sensitive to fires originated in the inboard portion of Zone II.

The installed extinguishing system provided rapid extinguishment of all Zone II fires until extensive accumulative damage from fires destroyed the integrity of the zone. Fireproof protection incorporated in the nacelle was very effective in performing its intended function. Most susceptable to damage by fire was the aluminum portion of the nacelle, especially aluminum receptacles for camlock-type fasteners, an aluminum ventilation louver panel in the top aft portion of Zone II, and aluminum ribs, formers, and baffles inside the nacelle in the path of fire. The fire damage to the engine and accessories was insignificant in regard to engine operation.

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INTRODUCTION

Purpose

The purpose of this project was to obtain, through full-scale fire tests on a small fuselage-mounted turbojet engine and nacelle installation, general design criteria which would enhance in-flight fire safety of this and similar installations. The scope of the project encompassed the determination of flammable fluid ignition hazards on engine hot surfaces, flame paths, fire detection, fire extinguishment, and fire resistance aspects of the installation.

Background

The program was originated at the request of the Federal Aviation Administration's Flight Standards Service, through the Aircraft Development Service. Uninterrupted testing began July 1, 1967, and was completed June 30, 1968.

Description of Equipment

The National Aviation Facilities Experimental Center's (NAFEC) Five-Foot Fire Test Facility was utilized for the full-scale test work. This facility had a 20-foot-long by 5-foot-diameter cylindrical test section. Airflow through the test section was induced by ejector pumping of two Pratt and Whitney J-57 turbojet engines whose exhausts were directed into a mixing section downstream of the test section. The test facility is shown in Figure 1.

The test article was the left inboard fuselage-mounted engine and nacelle of the Lockheed C-140 (Jet Star) airplane. This installation was normally a twin-engine siamese nacelle; however, limitation of the fire test facility's test section size necessitated cutting off the outboard portion of the siamese nacelle and installing only the inboard portion with its engine in the test section.

Each nacelle was divided into two fire zones by a vertical transverse stainless steel fire seal at Nacelle Station 117 (the main engine mount location in the nacelle was designated as Nacelle Station 100). Part of this fire seal was attached to the engine and consisted of an engine combustor shroud which extended aft 12.5 inches to the vertical section. The vertical section was mated with a vertical firewall collar built into the nacelle and was sealed by means of a fire-resistant tadpole tape compression seal. Also, for each twin-engine pod there were two vertical stainless steel firewalls extending longitudinally the length of Fire Zones I and II. One was on the inboard side of the nacelle isolating the pylon and fuselage from the nacelle fire zones, and the other was on the outboard side of the inboard nacelle isolating the outboard nacelle fire zone areas from the inboard nacelle areas.

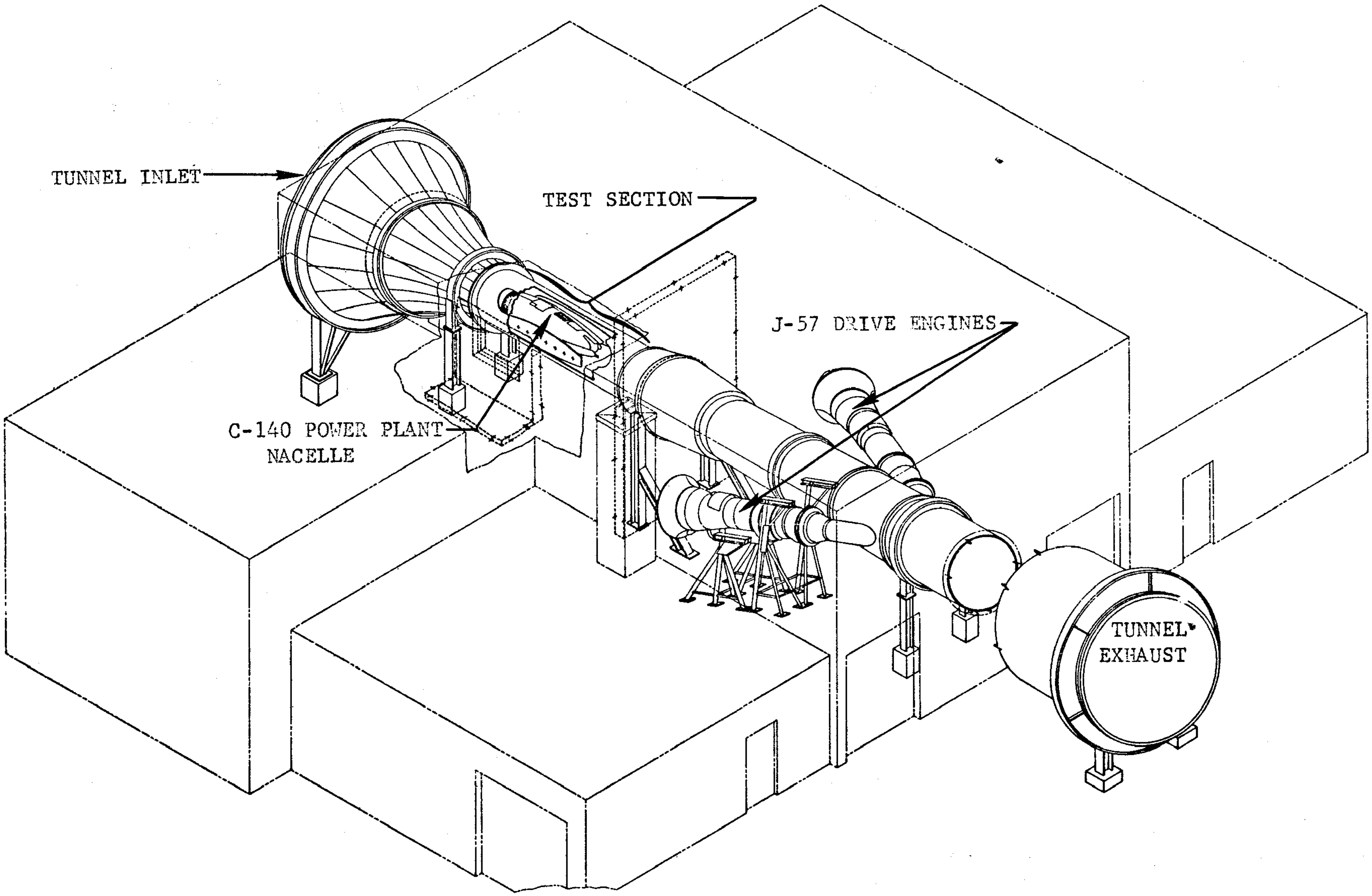


FIG. 1 FIVE-FOOT FIRE TEST FACILITY

Zone I, with a 10.0-cubic-foot free volume, encompassed the aft portion of the engine including the combustor, turbine, and tailpipe sections. Zone II, with a 12.6-cubic-foot free volume, encompassed the engine compressor and accessory sections.

A continuous-type fire detection system was provided for Zone II, and a separate continuous-type overheat detection system was provided for Zone I of each nacelle. The powerplant fire-extinguishing system provided extinguishment capability for Zone II of each nacelle only. Isolation of flammable fluid systems from the hot section of the engine (Zone I) by a vertical fire seal was a design feature of each nacelle.

Airflow into Zone II was provided by four 7/16-inch ID ram air tubes for cooling specific engine parts such as ignitor transformers and the main engine mounts. The outlet from Zone II for both ram air and engine bleed air (dumped into Zone II at and below approximately 81 percent of rated rpm (N_1) as observed during test operating conditions) was a louvered access panel located in the top aft portion of the zone. A captive air-cooling system was provided for cooling the starter/generator unit in Zone II. Cooling air was taken from the compressor inlet, ducted to a housing encasing the starter/generator, then ducted overboard. Cooling airflow to Zone I was provided through a 5.5-square-inch ram air duct located at Station 117, 5 o'clock position on the Zone I main access door. Air moving through this duct was directed onto the engine turbine case and expelled around the periphery of the engine exhaust nozzle assisted by ejector pumping action of the engine exhaust. A small spring-loaded flush air inlet door located just aft of the firewall on the inboard upper portion of Zone I was also provided for ventilation of this zone. This door was closed and sealed during this test program. The general features of the nacelle are shown in Figure 2.

The test engine was a Pratt and Whitney JT-12A-6 rated at 3,000 pounds maximum thrust. This turbojet engine has a nine-stage axial flow compressor and a two-stage axial flow turbine. It has interstage bleed ports at the fourth compressor stage which prevent compressor stall during engine acceleration. These ports were open from engine start to approximately N_1 = 81 percent rated rpm. Also, bleed air was supplied from the compressor ninth stage through a closed duct system for engine and nacelle inlet anti-icing and for fuselage pressurization.

The engine controls, fire detection indicators, extinguishing system controls, fuel-to-fire and ignitor controls as well as data collection equipment were centrally located in a test control room adjacent to the test section. A listing of the instrumentation used to monitor and record test data is provided in Table 1.

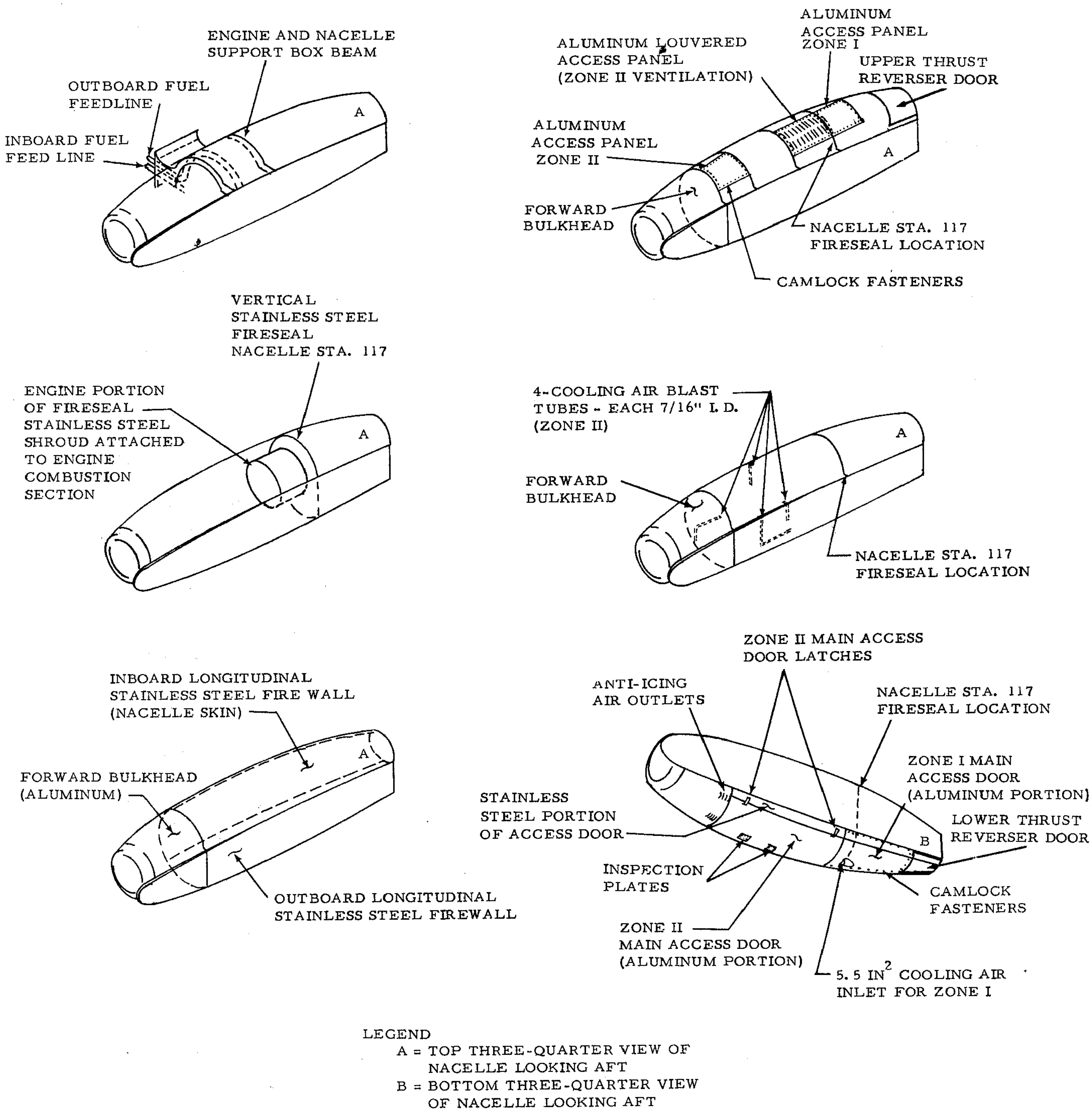


FIG. 2 GENERAL FEATURES OF THE TEST NACELLE

TABLE 1

SUMMARY OF INSTRUMENTATION

	Parameter	Location	Sensor	Transducer	Indicator	Record
1.	Nacelle Cooling Air Temperatures	Zone II - 24 Positions Zone I - 24 Positions Main Structural Beam Void Space - 4 Positions	30 Gauge Wire Probes	Type K Thermocouple Range: 0-2300°F	Self-balancing Potentiometers	Strip Chart
2.	Engine Metal Temperatures	Zone II - 3 each Diffuser and Combustor Fire-Seal Shroud Zone I - 3 each Combustor, turbine Outlet, tailpipe Sections	20 Gauge Wire Probes	Type K Thermocouple Range: 0-2300°F	Self-balancing Potentiometers	Strip Chart
3.	Other Metal Temperatures	Main Structural Beam - 4 Positions	20 Gauge Wire Probes	Type K Thermocouple Range: 0-2300°F	Self-balancing Potentiometers	Strip Chart
4.	Overpressure	Zone I	Pressure Transducer	C.E.C. Type 4-312-0002 Range: 0-25 psi ABS	Oscillograph	Strip Chart
5.	Nacelle Airflow	Zone I	Pitot-static Pressure Probe	Manometer Range: 0-60 inches HG ABS	Column of Mercury	Visual

TABLE 1 (continued)

SUMMARY OF INSTRUMENTATION

	Parameter	Location	Sensor	Transducer	Indicator	Record
6.	Test Fluid Pressure		Pressure Transducer	Teledyne Type 217-SA Range: 0-600 psig	Teledyne 237R Indicator	Visual
7.	Test Fluid Temperature		Thermal Electric Probe Model # 5D2711E	Type T Thermocouple Range: -300 to +700^{o}F	Potentiometer Type Indicator	Visual
8.	Engine rpm N_1	Engine Accessory Section	Tach-generator	G.E. 2CM14AAB-1 Range: 0-108% rated rpm	G.E. 8DJ81CAA Indicator	Visual
9.	Engine Exhaust Gas Temperature	Engine Exhaust Section	Engine Probe (4 probes)	Type K Thermocouple Range: 0-2300^{o}F	Potentiometer Type Indicator	Visual
10.	Tunnel Airflow		Tunnel Wall Static Ports	Manometer Range: 0-60 inches HG ABS	Column of Mercury	Visual

DISCUSSION

Hot-Surface Ignition Hazard

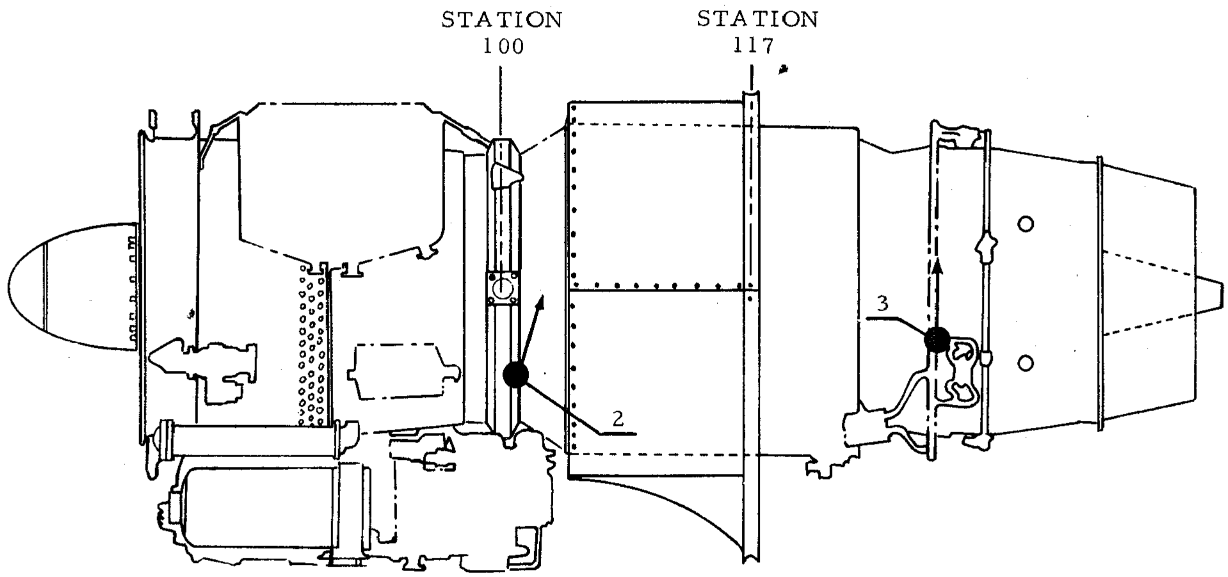
The hazard of igniting jet engine fuels and aircraft hydraulic fluids on the surfaces of an operating engine was investigated. The investigation was limited to two jet engine fuels (JP-4 and Jet A-1) and one hydraulic fluid (Military Specification 5606) in Zones II and I, with the normally configured Zones II and I, and one fuel (Jet A-1) in Zone I with a modified Zone I configuration. The fuel was heated and released as a spray at two locations in both Zone II and Zone I of the nacelle. Figure 3 shows these fuel release locations and contains a description of each release location. The fuel spray was directed so as to impinge on the engine diffuser case just ahead of the combustor section in Zone II and on the turbine outlet case in Zone I. These were areas where maximum engine surface temperatures were known to exist in each zone.

The test procedure for each test was essentially the same. The test engine was operated at military rated thrust (MRT), and the test facility airflow was adjusted to the desired Mach number. When all temperatures (engine case and ambient air temperature within the fire zone) were stabilized, fuel was released on the engine case for 2 to 3 minutes followed by engine speed reduction to idle. Fuel release was continued for 1 minute after power reduction to idle to investigate the possibility of hot-surface ignition during or after this transient power operation. Other tests were conducted in which the procedure was changed to include power reduction from MRT to a cruise setting for 1 minute, followed by a power increase to MRT for 1 minute, and finally a reduction in power to idle for 30 seconds before shutdown. Fuel release was continued throughout this procedure.

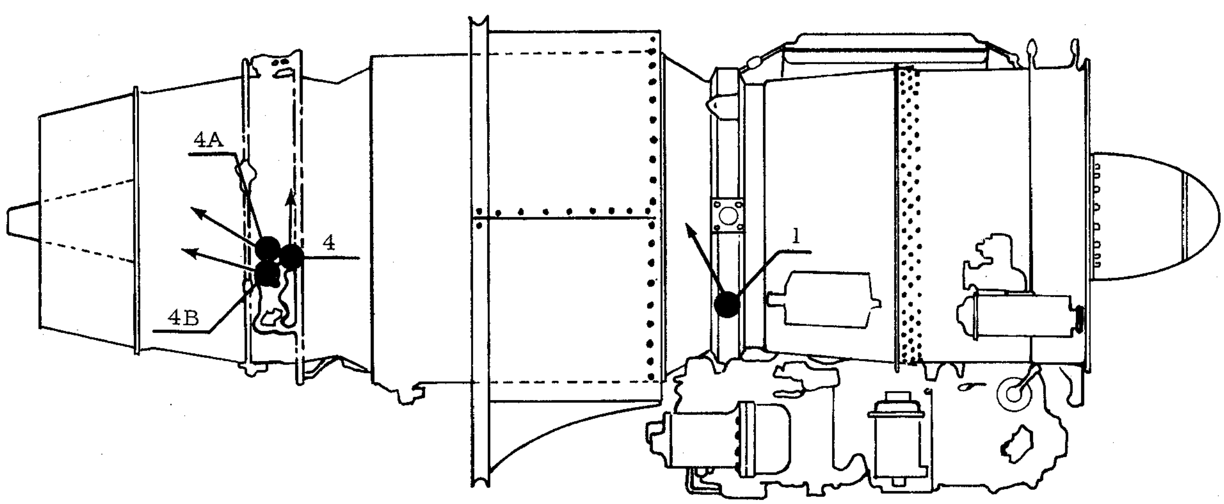
Figure 4 shows the engine operation and fuel release schedules for the hot-surface ignition tests.

Table 2 provides the environmental conditions and results of all hot-surface ignition tests conducted in Zones II and I of the normal nacelle configuration. Table 3 provides the environmental conditions and results of all hot-surface ignition tests conducted in Zone I when the normal configuration of Zone I was changed by reducing the size of the ram air inlet to this zone. Table 4 provides the environmental conditions and results of hot-surface ignition tests conducted in Zone I when the ram air inlet to this zone was closed completely.

Table 2 shows that there was no ignition of the flammable fluids (JP-4, Jet A-1, and Military Specification 5606 Hydraulic Fluid) released in Zones II and I, when the normal nacelle configuration was maintained. During the tests in which the flammable fluids were released in Zone II (the forward engine compartment), excess fuel was observed to leak out at the aft mating surface of the main access door to Zone II, run along



Nozzle Location:
2- Zone II, Nacelle Sta. 102.5, 7 o'clock; directed to spray fuel on the diffuser case at 9 o'clock
3- Zone I, Nacelle Sta. 128.5, 7 o'clock; directed to spray fuel on the turbine case at 9 o'clock



Nozzle Location:
1- Zone II, Nacelle Sta. 100, 4 o'clock; directed to spray fuel on the diffuser case at 3 o'clock
4- Zone I, Nacelle Sta. 128.5, 3:30 o'clock; directed to spray fuel on turbine case at 3 o'clock
4A- Same as 4 except that nozzle was directed to spray fuel on exhaust case at 3 o'clock 3" aft of turbine case
4B- Same as 4 except that nozzle was directed to spray fuel on horizontal centerline at the mating flange of the exhaust and tailpipe case

FIG. 3 FUEL RELEASE LOCATIONS FOR HOT-SURFACE IGNITION TESTS

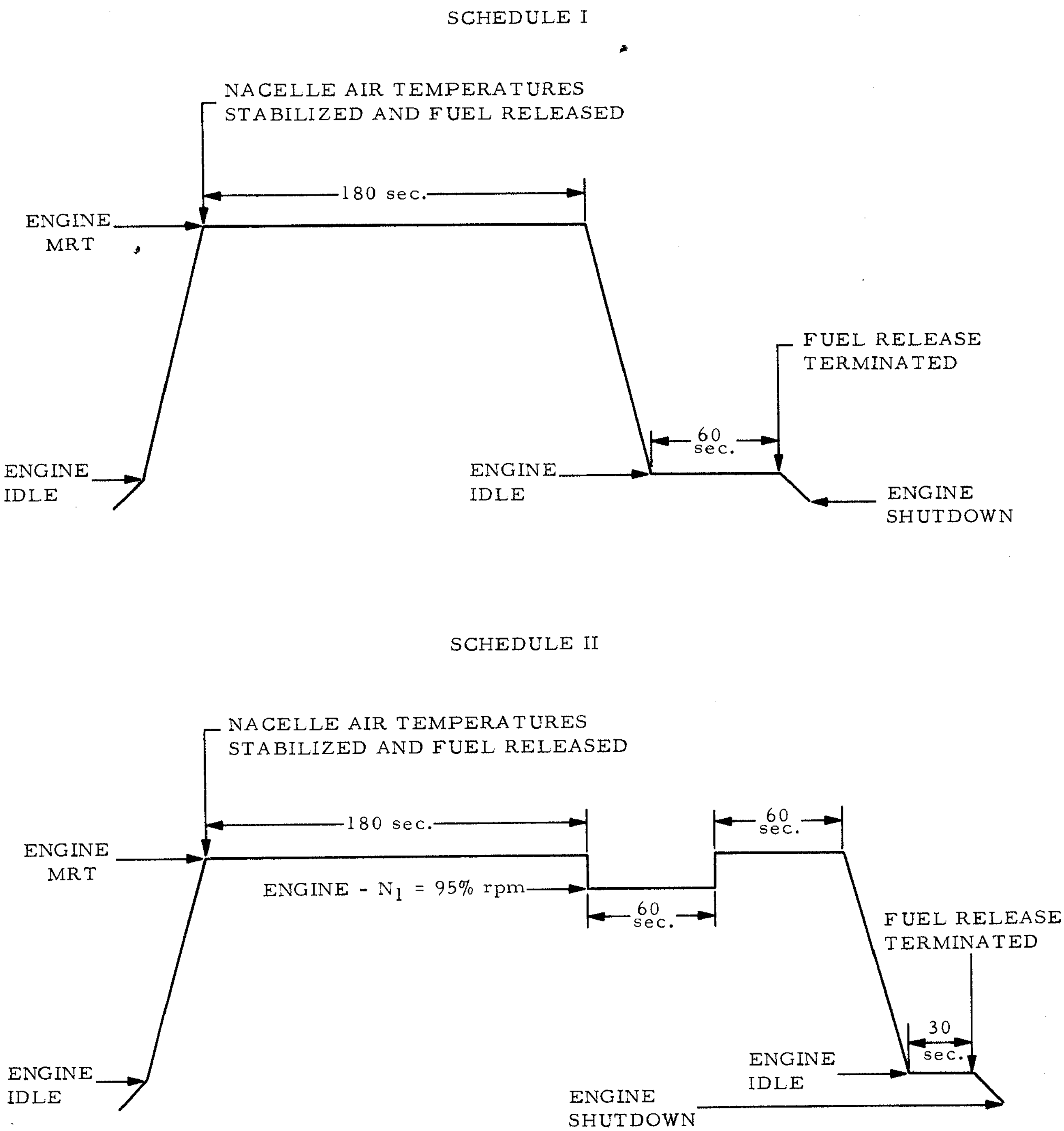


FIG. 4 TEST ENGINE POWER AND FUEL RELEASE SCHEDULES FOR HOT-SURFACE IGNITION TESTS

TABLE 2

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONES II AND I WITH THE NORMAL NACELLE CONFIGURATION

Run Nos.	Fluid	Nozzle Location (1)	Fluid Flow Rates (gpm)	Fluid Pressure Range (psi)	Fluid Temp. Range (°F)	Exhaust Gas Temp. Range @ MRT (°F)	Case Temp. @ MRT (2) (Min/Max °F)	Cooling Air (3) Temp. @ MRT (Min/Max °F)	Nacelle Air-flow @ MRT (lb/sec)	Results and Remarks
1 thru 6	JP-4	1, Zone II	0.1, 0.3, 0.56	345 - 570	122 - 195	---	455/485	95/200	0.2 (4)	No ignition (6)
7 thru 10	Jet A-1	1, Zone II	1.1, 0.3, 0.56, 0.1	320 - 565	186 - 234	1148 - 1157	420/510	110/220	0.2	No ignition (6)
11 thru 14	Jet A-1	2, Zone II	0.1, 0.3, 0.56, 1.1	340 - 660	195 - 263	1148 - 1157	440/515	100/180	0.2	No ignition (6)
15 thru 17	5606 Hyd. Fluid	2, Zone II	0.1, 0.3, 0.56	350 - 385	144 - 183	1157 - 1175	440/500	100/210	0.2	No ignition (6)
18 thru 20	5606 Hyd. Fluid	1, Zone II	0.1, 0.3 0.56	395 - 580	138 - 176	1175 - 1184	420/505	100/200	0.2	No ignition (6)
21 thru 23	5606 Hyd. Fluid	3, Zone I	0.1, 0.3, 0.56	385 - 575	136 - 176	1094 - 1175	830/1065	140/230	1.3 (5)	No ignition (6)
24 thru 27	Jet A-1	3, Zone I	0.1, 0.3, 0.56, 1.1	325 - 550	198 - 230	1130 - 1166	844/1085	125/250	1.3	No ignition (6)
28 thru 31	JP-4	3, Zone I	0.1, 0.3, 0.56, 1.1	260 - 485	194 - 244	1157 - 1175	825/1085	125/250	1.3	No ignition (6)
32 thru 33	Jet A-1	3, Zone I	0.3, 0.1	495 - 580	192 - 216	1148	830/1055	135/225	1.3	No ignition (6)

NOTES:
(1) See Figure 3 for description of location.
(2) Case temperature Zone II at Nacelle Station 103 in impingement area and Zone I at Nacelle Station 128.2 in impingement area.
(3) Cooling air temperature Zone II at Nacelle Station 98 close to impingement area and Zone I at Nacelle Station 129 close to impingement area.
(4) Calculated airflow to Zone II for facility Mach No. 0.5 and engine at MRT.
(5) Measured airflow to Zone I through the 5.5-square-inch ram air inlet duct for Facility Mach No. 0.5 and engine at MRT.
(6) See engine power Schedule I Figure 4.

TABLE 3

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONE I WITH JET A-1 FUEL AND REDUCTION IN AREA OF SECONDARY AIR INLET

Run Nos.	Nozzle Location (1)	Fluid Flow Rates (gpm)	Fluid Pressure Range (psi)	Fluid Temp. Range (°F)	Exhaust Gas Temp. Range @ MRT (°F)	Case Temp. @ MRT (2) (Min/Max °F)	Cooling Air Temp. @ MRT (3) (Min/Max °F)	Nacelle Air-flow Zone I (4) (lb/sec)	Inlet Air Duct Size Zone I (in.^{2})	Results and Remarks
34 thru 37	3	0.1, 0.3 0.56, 1.1	300 - 580	207 - 214	1175 - 1184	975/1180	145/280	0.6	2.75	No ignition (5)
38 thru 41	3	0.1, 0.3, 0.56, 1.1	360 - 585	167 - 228	1157 - 1220	1035/1160	150/260	0.3	1.35	No ignition (5)
42 thru 45	3	0.1, 0.3 0.56, 1.1	370 - 585	186 - 241	1202	1080/1225	155/380	0.15	0.65	No ignition (5)
46 thru 49	4	0.1, 0.3 0.56, 1.1	380 - 590	185 - 219	1193 - 1202	1095/1225	180/390	0.15	0.65	No ignition (5)

NOTES:
(1) See Figure 3
(2) Case temperature Zone I is at Nacelle Station 128.2 in impingement area.
(3) Cooling air temperature in Zone I at Nacelle Station 129 close to impingement area.
(4) Measured airflow to Zone I for Facility Mach No. 0.5 and engine at MRT.
(5) See engine power Schedule I Figure 4.

TABLE 4

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONE I WITH JET A-1 FUEL AND COMPLETE CLOSURE OF SECONDARY AIR INLET

Test No.	Nozzle Location(1) Type Release	Fluid Flow Rate (gpm)	Fluid Pressure/Temp. (psi/°F)	Exhaust Gas Temp. @ MRT (°F)	Case Temp. @ MRT (2) (°F) (Min/Max)	Cooling Air Temp. @ MRT (3) (°F) (Min/Max)	Air Temp. in Impingement Area Before Ignition (°F)	Case Temp. in Impingement Area at Fuel Release (°F)	Overpressure (psi)	Tunnel Velocity at Ignition (Mach No.)	Results
50	4/Spray	0.1	500/192	1166	1045/1205	180/440					No ignition (4)
51	4/Spray	0.3	595/207	1184	1050/1205	180/420					No ignition (4)
52	4/Spray	0.56	410/196	1184	1060/1220	180/370					No ignition (4)
53	4/Spray	1.1	400/216	1193	1070/1225	190/420					No ignition (4)
54	3/Spray	0.1	500/182	1184	1035/1220	180/					No ignition (4)
55	3/Spray	0.3	600/203	1175	1045/1220	180/					No ignition (4)
56	3/Spray	0.56	390/214	1175	1040/1225		235	1225	3.2	0.4	Ignition occurred 1.25 seconds after power reduction to idle (4).
57	3/Spray	0.56	385/212	1202	1030/1240	160/475					No ignition (4)
58	3/Spray	0.1	500/185	1229	1090/1250	180/530					No ignition (4)
59	3/Spray	0.3	600/210	1220	1040/1240	180/530					No ignition (4)
60	3/Spray	1.1	395/219	1202	1040/1230	180/540					No ignition (4)
61	4/Spray	0.56	400/216	1211	1040/1240	190/500	220	1235	1.2	0.3	Ignition occurred 9 seconds after power reduction to idle (4).
62	4/Spray	0.3	595/204	1202	1070/1230	190/500	230	1225	3.2	0.35	Ignition occurred 8.3 seconds after power reduction to idle (4).
63	4/Spray	0.1	490/176	1184	1100/1240	190/480					No ignition (4). Sealed Zone I cowl panels and thrust reverser.
64	4/Spray	0.3	600/187	1193	1060/1230	225/510	275	1230		0.5	Ignition occurred 30 seconds after acceleration from 95% to MRT, fuel shutoff (5).
65	4/Spray	0.1	485/203		1055/						No ignition (5)
66	4A/Spray	0.3	600/160	1202	1060/1150	220/490			1.0	0.5	Ignition 142 seconds after fuel release at MRT power (5) and (6)
67	4A/Spray	0.3	600/165	1202	1010/1165	225/460			0.75	0.5	Ignition directly after fuel release initiated (5) and (6).

TABLE 4 (CONTINUED)

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONE I WITH JET A-1 FUEL AND COMPLETE CLOSURE OF SECONDARY AIR INLET

Test No.	Nozzle Location(1) Type Release	Fluid Flow Rate (gpm)	Fluid Pressure/Temp. (psi/°F)	Exhaust Gas Temp. @ MRT (°F)	Case Temp. @ MRT (2) (°F) (Min/Max)	Cooling Air Temp. @ MRT (3) (°F) (Min/Max)	Air Temp. in Impingement Area Before Ignition (°F)	Case Temp. in Impingement Area at Fuel Release (°F)	Overpressure (psi)	Tunnel Velocity at Ignition (Mach No.)	Results
68	4A/Spray	0.3	610/172	1067					0.5	0.5	Ignition 87.7 seconds after increase power from 95% to MRT (5) and (6).
69	4/Spray	0.3	600/203	1211	1060/1150	245/490					No ignition (5)
70	4/Spray	0.3	600/194	1211	1060/1145	230/480	305	1145	0.5	0.35	Ignition 5.8 seconds after power reduced to idle (5).
71	4/Spray	0.3	580/207	1220	1090/1150	310/580					No ignition (5). Exhaust case insulation blanket removed.
72	4/Spray	0.3	580/203	1211	1085/1140	290/530					No ignition (5).
73	4B/Running	0.26	25/214	1202	1090/1210	300/525					No ignition (5).
74	4B/Running	0.13	25/199	1202	1095/1220	270/470					No ignition (5)
75	4B/Running	0.13	25/214	1202	1090/1195	235/520					No ignition (5)
76	4B/Running	0.26	25/219	1184	1090/1200	260/550					No ignition (5)
77	4B/Running	0.5	25/225	1184	1080/1185	270/500					No ignition (5)
78	4/Spray	0.1	505/212	1193	1085/1195	280/590					No ignition (5)
79	4/Spray	0.3	600/253	1166	1070/1185	270/565					No ignition (5)
80	4/Spray	0.3	600/226	1202	1085/1220	260/580					No ignition (5)
81	4A/Spray	0.3	600/230	1202	1100/1220	270/590					No ignition (5)
82	4A/Spray	0.3	600/239	1202	1100/1230	290/580					No ignition (5)
83	4/Spray	0.56	400/212	1202	1110/1235	280/570					No ignition (5)
84	4A/Spray	0.56	385/248	1220	1105/1220	280/590	255		2.5	0.3	Ignition occurred 14.9 seconds after power reduction to idle from MRT. (5)
85	4A/Spray	0.56	400/216	1220	1110/1230	280/500	255		2.8	0.3	Ignition occurred 16.2 seconds after power reduction to idle from MRT. (5)
86	4/Spray	0.56	405/234	1202	1090/1200	260/460					No ignition (5)
87	4/Spray	0.56	400/226	1220	1090/1200	250/485					No ignition (5)

TABLE 4 (CONTINUED)

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONE I WITH JET A-1 FUEL AND COMPLETE CLOSURE OF SECONDARY AIR INLET

Test No.	Nozzle Location(1) Type Release	Fluid Flow Rate (gpm)	Fluid Pressure/Temp. (psi/°F)	Exhaust Gas Temp. @ MRT (°F)	Case Temp. @ MRT (2) (°F) (Min/Max)	Cooling Air Temp. @ MRT (3) (°F) (Min/Max)	Air Temp. in Impingement Area Before Ignition (°F)	Case Temp. in Impingement Area at Fuel Release (°F)	Overpressure (psi)	Tunnel Velocity at Ignition (Mach No.)	Results
88	4/Spray	0.56	395/226	1211	1100/1190	270/520	275	1190	1.5	0.3	Ignition occurred 20 seconds after power reduction to idle from MRT. (5)
89	4/Spray	0.56	400/241	1202	1080/1180	265/460					No ignition (5)
90	4A/Spray	0.56	405/230	1202	1090/1190	270/590					No ignition (5)
91	4A/Spray	0.56	370/235	1211	1085/1190	270/580	255		2.0	0.3	Ignition occurred 10.9 seconds after power reduction to idle from MRT. (5)
92	3/Spray	0.56	385/250	1202	1070/1180	270/585					No ignition (5)
93	3/Spray	0.56	390/216	1202	1090/1195	280/600					No ignition (5)
94	3/Spray	0.56	/216	1211	1070/1190	260/510					No ignition (5)
95	3/Spray	0.56	405/226	1193	1070/1190	250/570	200	1070	4.5	0.5	Ignition occurred 51.7 seconds after fuel release at MRT (steady-state). (5)
96	3/Spray	0.56	405/241	1184	1050/1165	250/550	205	1050	3.6	0.5	Ignition occurred 182 seconds after fuel release at MRT (steady-state). (5)
97	3/Spray	0.56	400/243	1202	1040/1170	260/540					No ignition (5)

NOTES:
(1) Location of nozzles are shown in Figure 3.
(2) Case temperature in Zone I is at Nacelle Station 128.2 in fuel impingement area.
(3) Cooling air temperature in Zone I is at Nacelle Station 129 in fuel impingement area.
(4) See engine power Schedule I (Figure 4).
(5) See engine power Schedule II (Figure 4).
(6) Fuel nozzle was positioned so that the spray was directed toward the insulator blanket which covered the exhaust case section of the engine.

lower outside surface of Zone I and enter Zone I through the 5.5-square-inch secondary air inlet to this zone. An inspection of Zone I after a test in which hydraulic fluid was released, in Zone II, indicated that the excess fluid which entered Zone I through the air inlet impinged directly on the turbine outlet case, the hottest surface area in Zone I. However, there was no occasion where this caused ignition of the fuel. An inspection of Zone II, after each test, revealed that the fluid did not completely drain out of the zone and puddled in the lower aft portion of the main access door.

Table 3 shows that hot-surface ignition of Jet A-1 fuel released on the turbine outlet in Zone I did not occur when the secondary air inlet to Zone I was reduced to 2.75, 1.35, and .65 square inches. Table 4 shows that hot-surface ignition of Jet A-1 fuel released on the turbine outlet surface occurred under steady-state operating conditions and under transient operating conditions when the ram air inlet to Zone I was completely blocked off. In many cases an attempt to repeat the ignition under similar conditions was unsuccessful. On two occasions hot-surface ignition of released Jet A-1 fuel occurred soon after the fuel flow was initiated. Investigation of the fuel nozzle position after these tests indicated the nozzle which was originally directed toward the turbine outlet case had slipped so that the fuel spray was directed toward the heat blanket which covered the turbine exhaust case aft of the turbine outlet case. Therefore, it was surmized that this hot-surface ignition of the sprayed fuel was caused by the leaking of fuel on the exhaust case underneath the blanket.

Hot-surface ignition resulted in overpressures of 0.5 to 4.5 psi in Zone I of the nacelle. Damage to Zone I due to these overpressures was small. Camera coverage of these tests and inspection of the installation after ignitions showed that overpressures were relieved through (1) the closed-off ram air inlet to Zone I, (2) two pressure relief panels which were fabricated for the bottom access door, (3) the mating surfaces of this access door and a top access panel, and (4) the opening between the engine tailpipe and the nacelle. Slight deformation of the access panel and door between the camlock-type fasteners occurred during these tests.

Fire Detection and Fire Paths

The fire detection aspects in this powerplant installation were investigated looking towards general ways improvements could be made that would be applicable to similar installations.

The continuous-type fire detection system in nacelle fire Zone II and the separate overheat continuous system in Zone I are shown in Figure 5. In the aircraft, a single warning light for the two systems in each nacelle is provided in the cockpit. A steady warning light indicates a fire in Zone II, and an intermittent light indicates an overheat situation in Zone I. However, as part of the test setup a separate warning

TABLE 5

SUMMARY OF FIRE DETECTION TESTS IN ZONE II

Test	Test Engine Power	Facility(4) Mach No.	Fire(1) Location	Zone II Fire Detector Alarm Time (sec.)	Zone I Overheat Detector Alarm Time (sec.)	Fire Duration (sec.)
			FUEL FLOW TO FIRE - 0.3 GPM			
1	T.O.	0.5	5	4.2	6.2	12.5
2	T.O.	0.5	6	3.1	3.2	8.2
3	T.O.	0.5	7	3.7		7.3
4	T.O.	0.5	8	2.3		11.4
5	T.O.	0.5	9	7.9		12.3
6	Cruise	0.5	5	4.3	5.7	8.3
7	Cruise	0.45	5	4.9	6.5	8.6
8	Cruise	0.5	6	3.5	3.0	7.4
9	Cruise	0.45	6	3.1	3.3	6.7
10	Cruise	0.5	7	3.7		8.9
11	Cruise	0.45	7	1.7		4.2
12	Cruise	0.5	8	2.3		11.4
13	Cruise	0.45	8	2.7		7.1
14	Cruise	0.5	9	No alarm		8.5
15	Cruise	0.46	9	No alarm		5.8
16	Cruise	0.5	7A	3.2		9.2
17	Cruise	0.5	9A	3.1		9.1
18	N_1= 78% rpm (2)	0.5	5	2.8	3.8	8.0
19	N_1= 78% rpm (2)	0.32	5	2.6	3.7	6.6
20	N_1= 78% rpm (2)	0.5	6	3.8	3.1	7.3
21	N_1= 78% rpm (2)	0.3	6	No alarm	5.3	8.0